OPTIMAL ORIENTATION AND AUTOMATIC CONTROL OF EXTERNAL SHADING DEVICES IN OFFICE BUILDINGS

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ABSTRACT: Movable shading devices are often used to control solar radiation falling on large glazed surfaces in contemporary non-residential buildings. The paper presents some studies on optimal orientation of building in relation to the type of adopted shading devices and their control logic, in case of adjustable ones. Optimal orientation is the one minimising total annual primary energy demand, including artificial lighting and climatisation, giving the same thermal and luminous comfort. A case study, a room of an office building, has been analysed by means of computer simulations. The external wall of the room is entirely glazed. The effects of three different shading elements configuration are compared. The simulations have been performed in three Italian climates (Venice, Rome, Trapani).

Conference Topic: 1.1 Solar Architecture

1. INTRODUCTION

Nowadays wide glazed surfaces are used in offices buildings and an important task of the designer is to control solar radiation entering in the rooms [1]. External solar shading devices, fixed or adjustable, shall be designed considering the latitude and the orientation of building facade.

The orientation of a building fitted by passive solar systems, in temperate climates, has to maximise winter solar gain. To achieve this goal, main building axis is oriented East-West, in this way the main internal rooms facing South can receive a large solar contribution.

However if the rooms overlook on the main two sides, and if the energy needs are analysed for the whole year, a more detailed study shall be performed.

Other important factors can affect the design as the thermal mass of the building envelope, as the asymmetrical (referred to the solar noon) trend of external air temperature and of the office occupancy time profile. So it is not obvious that the better orientation can be either E-O or N-S.

This work presents some studies on the optimal building orientation in relation to the type of shading devices and their control logic, for adjustable ones.

The analysis has been performed by means of computer simulations.

Optimal orientation is the one that minimises total annual primary energy demand, including artificial lighting and HVAC, giving the same internal luminous and thermal comfort.

In the present study it is assumed that the office occupancy time profile is continuous from 9 to 19 hours, and that the HVAC plant is activated at 8 hours.

2. THE DATA

2.1 The office module

The case study is a room of an office building with two working places. The room’s dimensions are 6 m x 5 m, 3.3 m high. The external wall that is on larger side is entirely glazed. All the other five surfaces delimiting the room are assumed to be adiabatic. Figures 1-2 shows the building plant for a typical floor and a cross section of an office module, a central corridor connects the rooms whose windows are placed on the longer sides of building.

The external wall is composed, from the exterior to the interior, as follows: adjustable louvers, double glazing of 0.004 m thickness with 0.006 m of air gap, and internal diffusing blind.

Building structure is made up by reinforced concrete. Internal walls are in brick, 0.08 m thick, with 0.02 metres thick plaster on both sides. Floors are built in brick and reinforced concrete 0.3 m thickness. The assumed value of thermal capacity per unit area is 136 KJ/m²·K for internal walls, 377 for the floor.

The heating load, comprehensive of heat loss throughout the external wall and ventilation rate of 40 m³/(hour person), is 200 W·K⁻¹.

The internal gains includes artificial light and the time average value of the sensible thermal fluxes due to two occupants (2 x 60 W) and two computers (2 x 350 W), during the utilisation time.

The HVAC plant is an air-and-water system, designed with primary air and fan coil units.
Figure 1: Plant of a typical floor.

Figure 2: Cross section of the office module
2.2 Shading elements control logic

Three different configurations of solar control devices have been analysed:

- no external shading elements,
- external fixed louvers 45° tilted,
- automatically adjustable louvers with control logic (here called "seasonal") that allows at each time the entrance of just the useable solar radiation, in order to minimise the energy needs for climatisation.

In the third configuration we suppose that at each time a computer code calculates the necessary louvers angle and adapt louvers position by means of electric engine. This code perform an approximated energy balance of the room using as input the measured external air temperature and an equivalent room's thermal capacity, then it calculates the value of the solar gain required to meet internal comfort. If measured solar radiation is higher than the needed one, the program calculates the louvers angle that is required to make the first equal to the second.

In all the cases an internal diffusing blind can be lowered for spread light, if necessary, in order to avoid internal glare phenomena.

To compare energy balance of the same room when only the orientation is changed, the louvres have been imposed for each orientation (for North one also). As consequence there is homogeneity in calculations of view factors (windows-sky) and shadows.

3. THE CALCULATION’S PROCEDURE

3.1 Energy analysis

The first step is to perform the energy analysis for a single module, then the same job was performed on a couple of modules with opposite orientation. The average energy demand of the coupled modules gives an indication about the part of building energy demand that changes with orientation.

As first step, the better orientation of building main axis has been found among the following: North-South, East-West, NE-SW, NW-SE and heliothermic axis (19° displaced from the N-S towards the NE-SO orientation). As second step, slight variations, has been explored to find the orientation that minimises total energy need.

The analysis has been performed for three Italian climatic zones: North (Venice 45.5°N), Middle (Rome 41.8°N) and South (Trapani 37.9 °N).

3.2 The computer codes

The computer codes utilised for the simulations are the followings: Ener_lux, Midas and Comfort [2,3], see the bloc diagram in Figure 3.

They allow the simulation of the building behaviour concerning thermal balance, lighting comfort and thermal comfort. Automatic feedbacks on movable devices for comfort control are also simulated.

The input data are the hourly values of climatic data in monthly typical days, the geometric and thermal characteristics of the building.

The first code calculates hourly values of solar gains and daylight levels inside the room. Simulation of "seasonal control logic" involves louvers position calculation. This is made in two steps. As first, hourly solar gain with external louvers parallel to sun beams is calculated; as second step this actual value is compared with the pre-calculated value of useable solar gain. During the cooling period, this usable solar gain is zero. If the first value is higher than the second one the program calculates the louvers angle required to reduce the entering radiation to the needed one.

A second control is performed on the glare level from daylighting near the working positions. As first condition, program verifies the absence of direct radiation on visual task, that can cause disability or veiling glare. As second condition Daylighting Glare Index (DGI), concerning discomfort glare, is calculated by means of Cornell formula. If one of the two types of glare is out of acceptable range the program simulates blind’s lowering and repeats the hourly simulation-step.

As final task the code calculates the level of luminous flux that the lighting plant shall done to reach lighting comfort; the related primary energy needs and thermal fluxes, that the lamps gives to the indoor air, are calculated too.

The second code, Midas, simulates hour by hour the dynamic thermal behaviour of the room, taking into account solar and internal gains, including artificial lighting (from the results of Ener_lux). The code output is the primary energy need for climatisation and artificial light plant.

The third code uses values of the indoor air and internal surfaces temperatures to calculate thermal comfort indexes, PMV and PPD, as defined by ISO 7730 and the equivalent EN standard.

If PMV is out of comfort range, the internal set-point temperature is modified and the simulation-step is repeated. The user shall put into practice manually this feedback by modifying the input file. Data from input file are available to take into account yearly usual clothing variations and metabolic value related to human activity.
MIDAS
Pre-elaboration without control actions

Usable solar gain to meet thermal comfort in each hourly step of each monthly typical day

- Latitude
- daily Solar Radiation in each monthly typical day [Wh]

Geometric Description of the room

ENER_LUX

In each hourly step

Without control actions

Blades tilt modifying to meet thermal requirements

Calculation of:
- average value on glazed surface of energy and luminous fluxes (three components)
- transparency coefficients of glazed surfaces

Energy check:
- tolerable direct radiation on occupants,
- energy gain not bigger of utilisable value.

Calculation of illuminances on internal surfaces

Lowering of internal screens and new calculation of transparency coefficients of glazed surface

Controls about quality of luminous environment

not yes

Calculation of integrative luminous fluxes from electric light plant and related thermal fluxes given to the room

Relatively to each external surface of the room: hourly values of three impinging sun radiation components and transparency coefficients of glazed surface, comprehensive of internal screens if presents

Hourly values of thermal fluxes from electric light

- Latitude
- daily Solar Radiation in each monthly typical day [Wh]
- daily maximum air Temperature and daily excursion in each monthly typical day

Informations about climatisation plant and set-point temperatures

COMFORT

Control on thermal comfort (calculation of PMV e PPD)

The calculated value of energy demand is accepted

not yes

The calculated value of energy demand is accepted

Modifying of set-point temperatures

MIDAS

Simulation of dynamic thermal behaviour of the room with hourly step in each monthly typical days (heat balance method)

Monthly and annual primary energy demand

temperatures of each thermal zone (node)

Informations about climatisation plant and set-point temperatures

Informations about electric light plant

Geometric and thermal description of each thermal zone (RC nodes model)

Informations about climatisation plant and set-point temperatures

Figure 3: Bloc diagram of calculation's procedure.
4. THE RESULTS

Results of the simulations are resumed in the diagrams reported in this paragraph, their analysis support the following considerations.

With all the control logics here compared, and in all the climates the better facade orientation of the single module is the South one. Even if the South-oriented module is coupled with a North-oriented one their average energy demand is the lowest respect to the other orientations. Then the optimal orientation of the building main axis results to be the East-West.

Nevertheless climate and more control logic influence the differences in energy demand related to different orientations.

4.1 Configuration without external louvres

The analysis of this configuration is useful mainly to explain, in different climates, the amount of variation of different energy demands: heating, cooling and lighting.

Despite of the large glazing areas, heating needs are in general not remarkable because of the high internal gains in the office rooms. Also in climate of Venice daily value of these contributions is double of the heating plant one; the last being concentrated in the early hours of the morning. Both these contributions are very higher than the solar gain (e.g. Figure 4).

In all the simulated climates, most relevant energy demand is related to cooling. Also in cold climate as Venice, variations of heating energy demand with orientation have a low influence on variation of total energy demand; the last being influenced mainly by cooling and secondly by lighting.

In Venice, energy demand for heating is the half part of cooling needs and it is comparable with lighting energy needs. Moving toward lower latitudes, energy demand for heating decreases and the energy request for cooling grows.

For a given orientation the energy needs due to the lighting is almost constant in different climates.

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**Figure 4:** Venice, office module facing South without external shading elements, energy balance of internal air node in the monthly typical days of January February and March.

Internal gains due to people and office equipments are separated from ones due to lamps.
Comparing different orientations of single module the following consideration can be made (e.g. Figures 5 - 6).

a) - The minimum total energy demand corresponds to the module facing South: its advantage is higher in the colder climate (Venice) because of energy saving both for heating and for lighting, being their sum higher than cooling disadvantage. In other climates, where the cooling energy demand is higher, advantage of South-exposure is smaller. At Trapani, total energy demand for North and South exposure becomes almost equal, here heating demand is really small and the lighting demand, bigger North exposure balances the lower cooling demand.

b) - In all climates the higher energy need correspond nearly to East orientation, and this is due to the cooling component that assume the highest value. The energy consumption decreases with orientation following this order: West, then North and finally South.

c) - The heating component too shows two peaks for East and West orientations but the second one is higher.

Figure 5: Venice, annual primary energy demand of the office module for different uses. Orientation is in X-axis.

Figure 6: Trapani, annual primary energy demand of the office module for different uses. Orientation is in X-axis.
An analysis of energy fluxes hourly profiles has been necessary to understand the reasons of this behaviour, that is different from the one of a residential building (e.g. Figure 7). In the last case the overheating problems are higher in correspondence of West orientation, because of higher values of external air temperature and solar radiation in the afternoon.

In this way we can observe that the higher cooling load of East orientation is due to the effect of module thermal capacity and office occupancy time profile.

In warm periods, more or less from April to September, in correspondence of East orientation solar radiation heats the internal masses of floor and vertical walls in the early morning; then these masses heat the internal air during the remaining part of the day. In correspondence of South and West orientation the internal masses are heated later, then the duration of heat exchange with internal air is shorter and it occurs also beyond the end of working time.

The effect of this behaviour on annual energy demand is a bigger cooling need and a smaller heating need in correspondence of East orientation.

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**Figure 7**: Venice, heat exchange between internal air and masses, comparison between three modules, facing South, East, West, in the monthly typical days of January, April and July

Another factor that contributes to decrease the energy demand for West orientation is the smaller internal gain due to electric light. In fact the number of working hours in the afternoon is higher than in the morning and the office facing West utilises in a better way the daylight, the difference in lighting energy demand between East and West orientation is nearly to 30%.
Analysing average energy need of coupled modules with opposite orientation differences between East and West orientation are mediated. The more convenient orientation of building main axes results to be East-West (e.g. Figure 8).

4.2 Configuration with automatically movable louvers

Previous simulations show that air conditioning is the more relevant component of office module energy needs. The seasonal control logic is aimed to minimise it: the louvers tilt angle is controlled to allow in each time the entrance of just the useable solar radiation. Hourly value of useable solar energy is pre-calculated for each climate and for each building orientation.

In Venice the useable solar energy assume the maximal value in correspondence of South orientation and it is concentrated in the morning. In the cold period the useable energy has the same value for East and West orientation but it is concentrated respectively in the morning and in the afternoon. In the less cold periods, because of higher external temperature of the afternoon, its value is smaller for West orientation. Later, during the period from November to March, no solar energy is useable.

In Rome, with a warmer climate than Venice, useable energy is always higher for East than for West orientation; during springtime there is the greatest difference. In Trapani the difference between East and West orientation is higher than in the other climates.

Analysing the single module, the lowest energy consuming orientation seems to be the South one. But this advantage is due exclusively to the lower lighting consumption, while energy demand for climatisation is almost constant with orientation. In fact, if overheating is avoided by means of louvers, the bigger cooling loads in correspondence of East and West orientation disappear.

Comparing the behaviour of a South-facing module with a North-facing one in winter period, we can observe that in the first case, after the first hours of the morning, the louvers angle aimed to avoid overheating, is such to intercept completely direct radiation and a great part of the diffuse. On the other hand on the North side the diffuse radiation falling on the windows is always maximised. Thus the daily solar gain in the two cases is similar.

In the coupled modules case the variation of their average total energy need as function of orientation is furthermore reduced, building energy need becomes practically indifferent to orientation (e.g. Figure 9).

A little benefit of the East-West orientation of the building main axis is present, but sensibly reduced respect to this one observed without solar control; only in the climate of Trapani the advantage of this orientation is a little more evident.

With seasonal control logic the only energy demand that is sensibly variable with orientation is the lighting one. But when we analyse a couple of modules with opposite orientation the average value of it is practically indifferent to orientation of building axis.
Figure 9: Venice, seasonal logic, annual primary energy demand for different uses of a couple of office modules with opposite orientation.

4.3 Configuration with external louvers 45° tilted

With this configuration not only the direct radiation but a good part of the diffuse also are always intercepted, then the energy demand is practically constant with changing of the axis orientation. The asymmetry of office working-time (respect to the solar noon) and the higher external air temperature during the afternoon can explain the small differences between symmetrical orientations (i.e. South - East and South - West).

It is interesting to observe that in the warmer climate, Trapani, the North oriented module, compared with the South-oriented, presents smaller consumption for heating and a higher consumption for cooling; this is due to the internal gain from electric light.

5. CONCLUSIONS

The simulation’s results offer the orientation East-West of the building axis as the better one in all the compared climates: variations of ±11° are not relevant for the energy needs.

The automatic control of louvers tilt angle, with seasonal logic, is in general the optimal configuration. It is the more suitable choice in Venice, where heating demand is more relevant and solar energy input is hardly influenced by the louvers tilt angle (e.g. Figure 10).

In Rome the benefits of this configuration as regard to the second (fixed louvers at 45°), are lower. In Trapani no relevant differences are found especially considering the whole building.

Analysing the single room in the climate of Trapani (e.g. Figure 11) the fixed louvers is a bit more convenient than seasonal logic for orientation between South and East; because both direct and diffuse solar radiation are shielded, and the energy cooling needs are furthermore reduced.

Absence of external shading devices (no shad.) is in general the worst configuration. Looking at a single office module, the only case in which no control by external shading should be preferable (respect to the other two configurations) is a single module facing North in Venice. Considering the whole building only in the same climate, and with the building axis East-West orientated, this configuration is more convenient of fixed louvres but less convenient of seasonal logic (e.g. Figures 12 - 13).
Both seasonal control and fixed louvres make unappreciable the effect of orientation on the energy needs. This is more evident in the climates of Rome and Trapani, while in Venice there are a small convenience for each building axis orientations situated between the SSO-NNE and NNO-SSE directions.

In this work no shadows from surrounding buildings are considered, the urban context and the morphology of the geographical site are ignored. An analyse of this aspects would require to simulate not only the behaviour of a couple of office modules but all the modules present in the building, because the urban shading profile is different for each one.
Figure 12: Venice, comparison of different control logics, total annual primary energy demand of a couple of office-modules for different building main axis orientations (on X-axis).

Figure 13: Trapani, comparison of different control logics, total annual primary energy demand of a couple of office-modules for different building main axis orientations (on X-axis).

REFERENCES

